Salt and water: a brief natural history

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The highest good is like water. Water gives life to ten thousand things and does not strive. It flows in places that men reject and so it is like the Tao.

Tao Te Ching, chapter 8

Practically every patient evaluation by a nephrologist involves a review of daily weights and ins/outs to make an assessment of salt and water balance. Indeed, to help establish our modern understanding of renal physiology and evolutionary theory, Homer W. Smith spent a great deal of time studying the African lungfish, a fascinating animal that cyclically adapts its salt and water balance to aquatic and drought environments.[1]

With this in mind, I looked forward to visiting a current exhibition at the American Museum of Natural History in New York City—Water: H_2O = Life (http://www.amnh.org/water). The exhibit was in New York until May 2008 and has begun an international tour. The walk-through exhibit, beginning with a section called 'Life in Water,' exemplifies how various plants and animals maintain water balance in a broad range of environments. The display of diagrams, models, a few living animals, and an explanation of the chemical properties of the water molecule leads to the next section, 'Blue Planet.' Here a large revolving globe depicts the relative locations and proportions of fresh water on the earth, and the role of water in the planet's climate and geography. Next, 'Water Works' highlights historic and modern ways in which water, particularly fresh water, is harnessed by humans — wells, dams, canals, and hydraulic power, and the allocation of fresh water for irrigation of crops and livestock — and the effect of these human-made structures on their surrounding ecologies. The next sections, 'Water Everywhere' and 'Not a Drop to Drink,' contrast life in the wettest and driest places on earth, including the Mekong River valley in Cambodia, frozen Arctic regions, the Ganges River, the Namib Desert in Africa, and the Atacama Desert in South America. Here one sees natural and human-made examples of desalination to manage the scarcity of fresh water. The 'Healthy Water' section follows and focuses on the high energy cost of bottled-water use, the risks of water pollution, and the important role of wetlands and microbes in the ecology and cycle of water throughout the environment. The final section, 'Regeneration,' describes the fragile nature of aquatic ecosystems and efforts to restore altered regions of Mesopotamia, the Mississippi Delta, and Mono Lake. The exhibit closes with stories of local community members who participate in various activities to maintain and protect fresh water in their communities.

The exhibition is intended to reach a wide audience from young children to adults; to pursue a broad range of goals from education on general scientific principles to the support of a particular advocacy agenda; and to cover a broad range of topics from hydrogen bonds to ecologic balance. On the days I went, I found school-aged children with their families, some of the children attentive and hanging on every word as their parents read the legends, others seemingly irreverent. Older attendees, with or without children, became young again as they meandered through, some experimenting with the hands-on model of a released dam or an adjustable microscope to see 'life in a drop of water.'

The large scope of such an exhibition precludes detailed discussion of each of its topics. Nonetheless, the organizers successfully illustrate the breadth and imagination required to approach complex problems such as salt and water balance.

Throughout the exhibit, one finds very interesting examples of adaptive mechanisms in comparative physiology of osmotic regulation in the most extreme environments. As Knut Schmidt-Nielsen has aptly written, "At first glance, these environments may seem very different, but from a physiologic viewpoint, fresh water is no more freely available in the sea than in the desert."[2]

Included here is the Texas horned lizard, which uses a natural gutter system to capture scarce rainwater in the Chihuahuan Desert of North America. The lizard broadens and arches its back and lowers its head to direct falling water toward its mouth via thin channels between horned scales. As technology recapitulates phylogeny, this bio-mimetic concept of rain harvesting is highlighted again later with human-made gutters draining into a large storage water pot from Sri Lanka.

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Figure 1 | The iguana *Amblyrhynchus cristatus.* One can see salt crystals near the nostrils, as these creatures secrete large amounts of hypertonic salt solutions. Copyright Rob Stewart/Animals Animals.

The camel's ability to extract the moisture of exhaled air in its intricate nasal passages, combined with the animal's high heat tolerance, obviating the need for perspiration, demonstrates how anatomy and physiology have helped it adapt to extremely arid conditions. The description fittingly implies the convergence of osmoregulation and thermoregulation in the organism.

In addition to its immense urine-concentrating capacity, the kangaroo rat has developed the behavioral adaptation of a primarily nocturnal existence. Similarly, African desert beetles have adapted by crawling atop sand dunes to harness the moisture from fog.

Among other animals exhibited, many are familiar to renal physiologists. Animals with access to abundant salt water, such as the Galapagos marine iguana and the albatross, have developed salt glands in the nasal region for extraction and excretion of excess salt to maintain their tonicity (Figure 1).

The fundamental differences in osmoregulation between marine fish and the shark are explained. The former, drinking large amounts of sea water, use their gills (specifically the chloride cells there) and kidneys to actively excrete excess salts and maintain a hyposmotic state relative to their environment; the latter maintains isosmotic balance with sea water with a very high urea concentration but a salt concentration similar to those of other vertebrates. There's even mention of the shark's well-known 'salt-excreting gland,' the rectal gland, a long-time favorite of renal physiologists,[3] which is instrumental in its osmotic balance.

Like the aforementioned camel and kangaroo rat, other animals have generated interesting solutions to physiologic problems of thermoregulation. In response to freezing temperatures, for example, the wood frog's ability to become hyperglycemic provides an antifreeze property and exceptional cold tolerance. In 'it takes a village' fashion, emperor penguins, which must thrive in temperatures well below 0 °C for months at a time, huddle together to minimize exposed surface area and thus reduce the metabolic cost of keeping warm.

Animals that alternate between aquatic and terrestrial existence must alter their mechanisms of gas exchange. The Atlantic mudskipper carries small chambers of water attached to its gills, and it uses other moist body surfaces with blood flow, such as the oral cavity or skin, for respiration. This is mechanistically different from the lungfish, which, as Homer Smith has put it, "took to swallowing air and thus invented lungs and prepared the way for the evolution of the terrestrial vertebrates."[4]

Certain physiologic principles are even attributed to the planet itself. The periodic ebb and flow of tides is likened to the pulse of the planet. The global ocean currents between tropical and Arctic regions are reminiscent of the countercurrent exchange mechanism we consider so crucial for urinary concentration. One can't help but speculate that nature's "toolkit" somehow extends beyond genetic regulation of morphologic variation.

Walking through the Water exhibit, one realizes the vastly different physiologic mechanisms at work among various organisms to maintain their respective internal milieus. Physiologists have long pursued better understanding of other organisms to shed light on human physiology. Like Homer Smith's work, this exhibit reminds us of the breadth of perspective and the value of insight that may be gained from understanding how other creatures have solved problems of homeostasis.

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